博 士 学 位 論 文

Doctoral Dissertation

内容の要旨

及び

審査結果の要旨

Dissertation Abstracts

and

Summaries of the Dissertation Review Results

第21号

The Twenty-first Issue

平成25年3月

March, 2013

The University of Aizu

はしがき

博士の学位を授与したので、学位規則（昭和28年4月1日文部省令第9号）第8条の規定に基づき、その論文の内容の要旨及び論文審査の結果の要旨をここに公表する。

学位記番号に付した「甲」は学位規則第4条第1項（いわゆる課程博士）によるものであることを示す。「乙」は学位規則第4条第 2 項（いわゆる論文博士）によるものであることを示す。

Preface

On granting the Doctoral Degree to the individuals mentioned below, abstracts of their theses and the theses review results are herewith publicly announced, in according to the provisions provided for in Article 8 of the Ruling of Degrees (Ministry Of Education Ordinance No.9, enacted on April 1, 1953)

The Chinese character, "甲", at the beginning of the diploma number represents that an individual has been granted the degree in accordance with the provisions provided for in Paragraph 4-1 of the Ruling Of Degrees (what is called "Katei Hakase," or the Doctoral Degree granted by the University at which the grantee was enrolled.), "乙", at the beginning of the diploma number represents that an individual has been granted the degree in accordance with the provisions provided for in Paragraph 4-2 of the Ruling Of Degrees (what is called "Ronbun Hakase," or the Doctoral Degree granted by the University at which the grantee was enrolled.)

目　　次

Contents

掲載順 Order	学位記番号 Diploma No.	学位 Degree	氏名 Name	論文題目 Dissertation Title	頁 Page
1	甲CI博第34号	博士(コンピュータ理工学)	唐　尊一 TANG, Zunyi	信号スパース表現のための辞書学習アルゴリズム Dictionary Learning Algorithms for Sparse Representation of Signals	4
2	甲CI博第35号	博士(コンピュータ理工学)	菊地　伸治 KIKUCHI, Shinji	クラウドコンピューティング環境におけるトランザクションの補償処理機構の研究 Compensation Mechanisms in Transaction Processing for a Cloud Computing Environment	7
3	甲CI博第36号	博士(コンピュータ理工学)	曾　徳沢 ZENG, Deze	双方向中継ネットワークと遅延耐性ネットワークにおけるネットワークコーディング Network Coding in Two-way Relay Networks and Delay Tolerant Networks	11
4	甲CI博37号	博士(コンピュータ理工学)	松本　和也 MATSUMOTO, Kazuya	CPU/GPU混在型システムにおける行列乗算と最短経路アルゴリズムの設計および性能最適化 Design and Performance Optimization of Matrix Multiplication and Shortest-Path Algorithms on Hybrid CPU/GPU Systems	14

5	乙論博第1号	博士(コンピュータ理工学)	前田　多可雄 MAEDA, Takao	零相関ゾーン系列集合の構成スキーム Construction Schemes of Zero Correlation Zone Sequence Sets	17

Name 氏名	TANG, Zunyi 唐 尊一 （タン ズンイ）
The relevant degree 学位の種類	Doctoral degree (in Computer Science and Engineering) 博士（コンピュータ理工学）
Number of the diploma of the Doctoral Degree 学位記番号	甲 CI 博第 34 号
The Date of Conferment 学位授与日	March 22, 2013 平成 25 年 3 月 22 日
Requirements for Degree Conferment 学位授与の要件	Please refer to the article five of "University Regulation on University Degrees" 会津大学学位規程　第5条該当
Dissertation Title 論文題目	信号スパース表現のための辞書学習アルゴリズム Dictionary Learning Algorithms for Sparse Representation of Signals
Dissertation Review Committee Members 論文審査委員	University of Aizu, Prof. DING, Shuxue (Chief Referee) University of Aizu, Prof. HAYASHI, Takafumi University of Aizu, Prof. ZHAO, Qiangfu University of Aizu, Associate Prof. WATANABE, Yodai 会津大学教授　丁　数学（主査） 会津大学教授　林　隆史 会津大学教授　趙　強福 会津大学准教授　渡邊　曜大

Abstract

The focus of this dissertation is dictionary learning for sparse representation of signals. Sparse representation is that based on a redundant dictionary that contains atoms, signals are described by sparse linear combinations of these atoms. Applications that use sparse representation are many and include compression, feature extraction, regularization in inverse problems, etc. To provide a sparse enough representation, constructing an effective redundant dictionary becomes very important. Recently, the method of learning a dictionary by adapting its component to fit a set of signal examples becomes more concerned as it has produced promising results in various applications.

This dissertation focuses on dictionary learning in sparse representation of nonnegative signals since signals and corresponding dictionary have nonnegativity limitations in some applications, e.g., multispectral data analysis. The goal of this dissertation is to design and develop dictionary learning algorithms based on NMF framework so as to provide fast and high efficient methods for data analysis. The components of this dissertation are as follows.

In Chapter 1, we introduce and overview the background, motivation and contributions of this research on sparse representation, and then we give a brief review on sparse coding, existing dictionary learning methods, and nonnegative matrix factorization technique in Chapter 2.

In Chapter 3, we propose a new sparsity measurement with a form of the determinant of a squared signal matrix. Comparing with the other measurements, the proposed one has several important advantages. One of the notable advantages is that it is smooth differentiable while the other measurements are not, so that it can be optimized more efficiently. By employing the sparsity measurement and the NMF framework, we further propose and investigate an algorithm, called NMF-DMS, which can be used for dictionary learning for sparse representation of signals. In the experiment of recovering synthesized dictionary, experimental results show the proposed NMF-DMS algorithm can recover most atoms in actual dictionary in lower levels of noise, and it performs better than the other two algorithms no matter what conditions. Experiments using natural images furthermore evaluate that the performances of the dictionaries obtained by NMF-DMS are very similar to those of

the dictionaries learned by well-known K-SVD. Under higher PSNR conditions, NMF-DMS dictionaries are better than K-SVD dictionaries.

In Chapter 4, we study the feature extraction based on the NMF framework, which can be viewed as a kind of dictionary learning. To improve the capability of NMF for sparse representation, we propose two sparse HALS algorithms based on HALS, in which L1-norm is employed to constrain the sparsity of dictionary matrix or coefficient matrix. Numerical experiments with a face dataset shows that the global-based and local-based features learning by the proposed algorithms are performed better in comparison with the other conventional algorithms. The features obtained by proposed algorithms are sparser. Furthermore, the proposed algorithms are more effective in extracting features and cost much less time than other algorithms.

In Chapter 5, we focus on the overcomplete dictionary learning for sparse representation of nonnegative signals. For this purpose, we present a sparse HALS algorithm by generalizing HALS,

in which a dictionary-coherence penalty term, which is for a more efficiency of the dictionary, and an $\ell 1$-norm-based sparsity penalty term are incorporated into the objective function. Results of experiments on dictionary learning show that the proposed SHALS can correctly learn a nonnegative overcomplete dictionary, no matter the objective signals are synthetic data or are natural images. Further experiment results demonstrate the potential applications of SHALS in the field of image processing, such as image denoising and feature extraction. In the experiment of image denoising, the denoising method using SHALS dictionary achieve highly competitive PSNR and SSIM performance outcomes compared to those of well known ProbShrink-SP and BLS-GSM methods, etc. In the experiment of feature extraction, the proposed method can also learn global-based and local-based features more effectively than other compared algorithms.

Finally, we summarize our work and plan our future work in Chapter 6.

Summaries of the Dissertation Review Results

Since the state of the paper submitted to IEICE Transactions on Information and Systems is currently Conditional Acceptance, although the condition is minor and easy to be satisfied, the result of "Judgment of the Final Review" will become valid once the formal acceptance letter for the paper has arrived.

Name 氏名	KIKUCHI, Shinji 菊地 伸治 （キクチ　シンジ）
The relevant degree 学位の種類	Doctoral degree (in Computer Science and Engineering) 博士（コンピュータ理工学）
Number of the diploma of the Doctoral Degree 学位記番号	甲 CI 博第 35 号
The Date of Conferment 学位授与日	March 22, 2013 平成 25 年 3 月 22 日
Requirements for Degree Conferment 学位授与の要件	Please refer to the article five of "University Regulation on University Degrees" 会津大学学位規程　第5条該当
Dissertation Title 論文題目	Compensation Mechanisms in Transaction Processing for a Cloud Computing Environment クラウドコンピューティング環境におけるトランザクションの補償処理機構の研究
Dissertation Review Committee Members 論文審査委員	University of Aizu, Prof. BHALLA, Subhash (Chief Referee) University of Aizu, Prof. TEI, Shigaku University of Aizu, Prof VAZHENIN, Alexander University of Aizu, Senior Associate Prof. KLYUEV, Vitaly 会津大学教授　バーラ　サバシュ（主査） 会津大学教授　程　子学 会津大学教授　ヴァジェニン　アレクサンダー 会津大学上級准教授　クリュエフ　ヴィタリー

Abstract

Together with making Cloud Computing reliable and dependable, we need to mature defining Service Level Agreements (SLA) for the quality assurances of services. Additionally, it is necessary to implement certain mechanisms in order to maintain the SLA further. In particular, the emerging inter-Cloud Computing environment which multiple entities of Cloud Computing participate has gradually taken its shape. In order to realize this inter-Cloud Computing environment, the Composite Web service (CWS) is a strongly applicable and promised candidate as the system foundation. However, the CWS which consists of multiple elemental services often has features of a transactional workflow applying the notion of a long lived transaction. And a compensation transaction handling the occurrence of an exception has the crucial role. However the design methodology for it has still remained immature in spite of several existing advanced studies. In particular, clarifying a concrete architecture for integrating Transaction-Aware together with the mechanism for maintaining SLA categorized as QoS-Aware has been ongoing. Even current major works also still have room for improvement. Based on the above, in this paper, the following two theses are selected as the main issues:

1. Thesis.1: At first, we will argue that we are currently facing an arising requirement about reconsidering a new transaction model in Service Oriented Architecture (SOA), which is more applicable for the Cloud Computing environment. Currently we have still had the ambiguous status around relationships among Cloud Computing architecture, SOA and transaction management including long lived transactions with compensations. Here, we will initially show the results of our preliminary analyzing around the above. Based on the extracted results, we will propose a new improved model of the compensation transaction in order to make the whole of a transaction more reliable and more applicable to the Cloud Computing environment.

2. Thesis.2: In order to establish the transaction management in SOA, which is more harmonized with features of QoS-Aware, we make the architecture of the compensation mechanism more concrete. So far, that architecture has tended to remain at the methodology and conceptual level.

As for the above thesis.1, based on our evaluation by using the numerical simulation, we conclude that our proposed compensation transaction model is faster and more effective in attaining the final definitive status of long lived transactions with robustness against inconsistency. This means our approach might potentially have certain advantages for realizing quick compensations for the huge number of transactions in a Cloud Computing environment. It can also be confirmed that there is potentially a high degree of applicability in Cloud Computing. Conversely, in regards to the thesis.2, we propose a new conceptual approach to realize a control in performance for CWSs. Compared with existing methods, the uniqueness of our method is a hybrid approach consisting of several technical elements such as Theory Of Constraints (TOC). The prominent contributions of this work are; (a)

Establishing a theoretical backbone of a new controlling principle in the service computing domain. (b) Defining a control framework with simulation functionality and applied policies with verification in multiple times. By applying the above approach, we could make the architecture of the compensation mechanism more concrete on the viewpoint of the software architecture. In particular, our approach might be more potential and more effective, because of the minimized references after detecting an exception. This might be meaningful for the scalable workflow management in future.

Chapter　1　:Introduction.

In this chapter, we will explain about the general matters such as the technical trends and their status. Then, we will also specify the targeted issues in this work.

Chapter　2　:Related Works.

In this chapter, we will briefly explain about related works.

Chapter　3　: Compensation Transactions for SOA.

Based on the background explanation in chapter.1, we have studied a new transaction model in SOA, and have proposed the 'Enhanced Rollback Migration Protocol (ERMP)'. In this chapter, we will describe ; (a) Outlines of ERMP in a simplified case, (b) A generalized algorithm of ERMP, (c) A semantic model including our hypotheses, (d) Evaluation method and its metrics. (e) Mathematical models. Then, (f) Characteristic properties.

Chapter　4　: SLA-Aware Composite Web Services.

In this chapter we will explain the reference models and theoretical aspects of the proposed method, which mainly consists of TOC, a set of policies for control operations and simulation utilities. Our contributions with this novel proposed method are; (a) Establishing a theoretical backbone for a new controlling principle in the service computing domain. (b) Defining a control framework, which has a simulation functionality and applies the policies under verification multiple times. Furthermore we also conclude that the simple feedback controlling approach under the TOC cannot function well.

Chapter　5　: Designing Compensation Mechanism.

In this chapter, we will present the result of our architectural design for run time and its principle for SLA management together with executing the compensations which handle exceptions during long lived transactions. In the result of our architectural design, the related components mentioned in the previous chapter.3 and chapter.4, are contained harmoniously. Our major contribution by this design is to clarify the framework of the software architecture, especially focusing on the run time, which has been ambiguous under the existing works so far.

Chapter　6　: Evaluation.

In this chapter, we will evaluate our approaches defined in previous chapter.1 individually. In section 6.2, we will talk about the evaluation related to ERMP. In section 6.3, we will mention the evaluation related to our method of maintaining the performance of CWS. In section 6.4, we will evaluate our compensation mechanism by comparing with the other research. Finally in section 6.5, we will show an applicable example in Personal Healthcare

Records (PHR).

Chapter　7　:Conclusion

The conclusion will be mentioned according to the defined theses.

Summaries of the Dissertation Review Results

During the examination, the members of the committee requested clarifications and details from the candidates. At the end of the examination, the review committee members discussed the candidate's thesis report and performance at the final examination. The review committee resolved that the dissertation does not have points that need substantial modifications and recommended an approval of its successful completion.

Name 氏名	ZENG, Deze 曾　徳沢　（ゼン　デゼ）
The relevant degree 学位の種類	Doctoral degree (in Computer Science and Engineering) 博士(コンピュータ理工学)
Number of the diploma of the Doctoral Degree 学位記番号	甲 CI 博第 36 号
The Date of Conferment 学位授与日	March 22, 2013 平成 25 年 3 月 22 日
Requirements for Degree Conferment 学位授与の要件	Please refer to the article five of "University Regulation on University Degrees" 会津大学学位規程　第5条該当
Dissertation Title 論文題目	Network Coding in Two-way Relay Networks and Delay Tolerant Networks 双方向中継ネットワークと遅延耐性ネットワークにおけるネットワークコーディング
Dissertation Review Committee Members 論文審査委員	University of Aizu, Senior Associate Prof. GUO, Song (Chief Referee) University of Aizu, Prof. TEI, Shigaku　・ University of Aizu, Prof. MIYAZAKI, Toshiaki University of Aizu, Prof. TSUKAHARA, Tsuneo Huazhong University of Science and Technology, Prof. JIN, Hai. 会津大学上級教授　グオ　ソン（主査） 会津大学教授　程　子学 会津大学教授　宮崎　敏明 会津大学教授　束原　恒夫 華中科技大学教授　JIN, Hai.

Abstract

Network coding (NC) has shown the promise of significant performance improvement in various application scenarios. In this dissertation, we study on the performance analysis and optimization of NC in wireless networks. We first discuss exclusive-or (XOR) based NC in two-way relay wireless networks. Although much work has shown that such NC scheme has shown great potential to promote the performance of two-way relay wireless networks, by extensive literature survey, we discover that no work can give an accurate performance analysis of NC in general two-way relay networks. Motivated by this fact, we first study the throughput of two-way wireless relay networks using XOR-based NC and explore how the maximum throughput can be achieved under a random medium access scheme, with interference-free assumption. Unlike previous analysis studies with some strict assumptions, we consider a more practical network where the structure of overhearing status between the intended receivers and the transmitters is arbitrary. We invent the concept of network coding cliques (NCCs), based on which a formal analysis on the network throughput is further made. The analysis shows that the maximum normalized throughput, subject to fairness requirement, is n $n+m$, where n is the number of transmitters and m is the number of NCCs in a two-way relay wireless network. We have also found that this maximum throughput can be achieved under a random medium access scheme when the medium access priority of the relay node is equal to the number of NCCs in the network. We then take practical medium access control and interference into our performance analysis framework. A widely concerned protocol, slotted ALOHA medium access protocol, is studied. Accordingly, the offered traffic loads as well as the transmission probabilities are considered. We apply our NCC concept and conduct a formal analysis on the network throughput. By stochastic analysis, we capture the dynamics on the relay buffer and obtain the closed-form expression of the network throughput as a function of traffic loads and the medium access probabilities of wireless nodes in ix a slotted ALOHA network. Then, we further derive the maximum throughput as well as optimal medium access probability at each node. Our study not only provide the first formal accurate analysis on the two-way relay slotted ALOHA wireless networks using XOR-based NC, but also indicates how to efficiently share the channel resource among the transmitters and the relay node by orchestrating the offered traffic load at the transmitters and adjusting the transmission probability at the relay node. We next investigate the performance optimization issue of random linear network coding (RLNC) in Delay/Disruption Tolerant Networks (DTNs). DTNs are different from conventional wireless networks and characterized by the lack of continuous or contemporaneous connections among wireless nodes. Only intermittent connectivities between mobile nodes in DTNs. Such unique feature makes existing routing solutions hardly to be applied directly in DTNs. Although epidemic routing is proved as with the highest delivery performance in DTNs thanks to its flooding nature, it does not handle multiple-packet transmission well. Hence epidemic routing using RLNC has been studied and proved as an efficient way to address multiple-packet transmission issue. However, epidemic routing using RLNC fails to handle bulk or stream-like data dissemination in DTNs due to several constraints. To address this problem, we consider a segmented network coding approach where

RLNC is conducted on segments such that decoding complexity could be substantially reduced. We first consider best-effort unicast applications in feedbackless DTNs and propose a double-buffer based pipeline segment network coding scheme and an efficient buffer management strategy, called DOSO ("Discard the Oldest & Serve the Oldest"), with the goal of maximizing the throughput performance in DTNs. Later, for reliable unicast in DTNs, based on our double-buffer based pipeline segmented network coding, we invent a new segmented method where the segment sizes are dynamically adjusted according to real-time network conditions such that both reliability and high efficiency are achieved. Through extensive simulation studies, the high efficiency of our segmented network coding policies is validated.

Key words: Performance Analysis, Performance Optimization, Network Coding, Twoway Relay Networks, Delay/Disruption Tolerant Networks, Opportunistic Routing

Summaries of the Dissertation Review Results

As a result of several-round dissertation review, the dissertation has been recognized as qualified for conferment for an academia degree.

The dissertation has 107 pages with seven chapters. In these chapters, performance analysis and optimization issues in two-way relay networks and delay tolerant networks are well presented. The dissertation is well structured and written. It is easy to follow and understand the research results. Several important contributions have been made. They are not only significant to the academia but also to the industry as the dissertation provides a significant guidance to practical use of network coding technique.

The main results obtained during the research and described in the dissertation are published in the following journals and conference proceedings:

1)   Deze Zeng, Song Guo, Hai Jin and Shui Yu, "On the   Maximum   Throughput   of Two-hop Wireless Network Coding," in Proceedings of the 2011 Wireless Communications and Networking Conference (WCNC 2011), 2011, pp.416-421, Mar. 2011, IEEE.

2)   Deze Zeng, Song Guo, Yong Xiang and Hai Jin, "On the Throughput of Two-way Relay Networks using Network Coding,"   IEEE Transactions on Parallel and Distributed Systems, accepted on Nov. 2012.

3)   Deze Zeng, Song Guo, Hai Jin and Victor CM Leung, "Segmented Network Coding for Stream-like Applications in Delay Tolerant Networks,"   Proceedings of the 2011 Global Telecommunications Conference (GLOBECOM 2011), pp.1-5, Dec. 2011, IEEE.

4)   Deze Zeng, Song Guo, Hai Jin and Victor CM Leung, "Dynamic Segmented Network Coding for Reliable Data Dissemination in Delay Tolerant Networks," Proceedings of the 2012 International Communications Conference (ICC 2012), pp. 63-67, Jun. 2012, IEEE.

Name 氏名	MATSUMOTO　Kazuya 松本　和也　（マツモト　カズヤ）
The relevant degree 学位の種類	Doctoral degree (in Computer Science and Engineering) 博士(コンピュータ理工学)
Number of the diploma of the Doctoral Degree 学位記番号	甲 CI 博第 37 号
The Date of Conferment 学位授与日	March 22, 2013 平成 25 年 3 月 22 日
Requirements for Degree Conferment 学位授与の要件	Please refer to the article five of "University Regulation on University Degrees" 会津大学学位規程　第5条該当
Dissertation Title 論文題目	Design and Performance Optimization of Matrix Multiplication and Shortest-Path Algorithms on Hybrid CPU/GPU Systems CPU/GPU混在型システムにおける行列乗算と最短経路アルゴリズムの設計および性能最適化
Dissertation Review Committee Members 論文審査委員	University of Aizu, Prof. SEDUKHIN, Stanislav (Chief Referee) University of Aizu, Prof. NIKISHIKOV, Gennadiy University of Aizu, Senior Associate Prof. HAMEED, Saji University of Aizu, Senior Associate Prof. NAKASATO, Naohito 会津大学教授　セドゥーキン　スタニスラフ　（主査） 会津大学教授　ニキシコフ　ジェナディ 会津大学上級教授　ハミード　サジ 会津大学上級教授　中里　直人

Abstract

Hybrid/heterogeneous computing systems containing multi-core CPUs and manycore GPUs are now popular for high-performance computing at a modest cost. However, developing high-performance programs on the hybrid systems remains challenging. This dissertation presents our approaches for dense matrix-matrix multiplication and solutions for the all-pairs shortest paths (APSP) problem on hybrid CPU-GPU systems. The dissertation firstly addresses the dense matrix-matrix multiplication problem, referred to as GEneral Matrix Multiply (GEMM) in Basic Linear Algebra Subprograms (BLAS) standard, on hybrid CPU-GPU systems. The double-precision GEMM (DGEMM) implementation was optimized in multiple levels. We examined, for the first time, effects of different memory access patterns in the DGEMM kernel on the performance and cache hit rate by changing its layout function on a GPU. Moreover, we designed and implemented GEMM algorithms which efficiently utilize the GPU by reducing the amount of data communication between the GPU and the CPU (host). As a result, our DGEMM routine can be run with high GPU utilization on the hybrid systems. The maximum performance of the routine is 472 GFlop/s and 921 GFlop/s, using one GPU and two GPUs of a hybrid system, respectively. Based on the study on the matrix multiplication, we designed blocked algorithms for solving the all-pairs shortest paths (APSP) problem in weighted graph on hybrid CPU-GPU systems. The dissertation secondly presents the blocked APSP algorithms. In the APSP problem, computing the shortest-path distance matrix and also the xv shortest-path construction matrix are required for the solution. We initially designed a blocked algorithm for computing only the distance matrix, and then, developed a blocked algorithm for computing both matrices. Our developed algorithm is, to our best knowledge, the first high-performance method to compute both matrices at the same time on a hybrid system. In our APSP implementation, the two most compute intensive parts of the algorithm are performed on the GPU. One of the most intensive parts is to solve the APSP sub-problem for a block, and the other part is a matrix-matrix "multiplication" in min-plus algebra for the APSP problem. The APSP implementation is currently the fastest APSP solution in dense graph on a single-node system and the single-precision performance is up to 1.1 TFlop/s. Finally, the dissertation describes an auto-tuning system with a code generator for fast matrix multiply kernels in Open Computing Language (OpenCL) and its performance portability among different processors. Our auto-tuning system can search a large number of kernel patterns and it can produce high-performance DGEMM and SGEMM kernels. The performance evaluation is conducted on twoAMDGPUs (Tahiti and Cayman), two NVIDIA GPUs (Kepler and Fermi), and two CPUs (Intel Sandy Bridge and AMD Bulldozer). Results of this evaluation show that storing matrix data in a block-major order increases the performance of GEMM kernels on all evaluated processors. Our GEMM implementations on the AMD GPUs show higher performance than the highly tuned vendor library while the implementations on the NVIDIA GPUs are comparable. The Tahiti GPU showed the highest performance among these processors and the maximum DGEMM and SGEMM performance are 863 GFlop/s (91% of the peak performance) and 3.05 TFlop/s (80%), respectively. These 91% and 80% efficiencies are currently higher than any previously reported efficiencies on the GPU.

Summaries of the Dissertation Review Results

The review committee agreed that the applicant is qualified for his doctoral degree, considering his publication records, dissertation, and presentation..

Name 氏名	MAEDA, Takao 前田 多可雄 （マエダ タカオ）
The relevant degree 学位の種類	Doctoral degree (in Computer Science and Engineering) 博士（コンピュータ理工学）
Number of the diploma of the Doctoral Degree 学位記番号	乙CI博第 1 号
The Date of Conferment 学位授与日	March 22, 2013 平成 25 年 3 月 22 日
Requirements for Degree Conferment 学位授与の要件	Please refer to the article five of "University Regulation on University Degrees" 会津大学学位規程　第5条該当
Dissertation Title 論文題目	Construction Schemes of Zero Correlation Zone Sequence Sets 零相関ゾーン系列集合の構成スキーム
Dissertation Review Committee Members 論文審査委員	University of Aizu, Prof. HAYASHI, Takafumi (Chief Referee) University of Aizu, Prof. OKAWA, Satoshi University of Aizu, Prof. DING, Shuxue University of Aizu, Associate Prof. WATANABE, Yodai 会津大学教授　林　隆史　（主査） 会津大学教授　大川　知 会津大学教授　丁　数学 会津大学准教授　渡邊　曜大

Abstract

There are many applications of sequences, and many of them make use of orthogonal sequences. Some of the most powerful of these are the zero-correlation zone (ZCZ) sequence sets. Let L, N, and z be integers. A ZCZ sequence set of length L, cardinality N, and ZCZ size z is a set X that satisfies the following properties:

(1) X contains N sequences,

(2)   the length of each sequence in X is L,

(3) $R_{x,y}(\tau)\begin{cases} \neq 0, & \text{for} \quad \tau = 0, x = y \\ = 0, & \text{for} \quad \tau = 0, x \neq y \\ = 0, & \text{for} \quad 0 < |\tau| \leq z \end{cases}$

where $x, y \in X$ and $R_{x,y}$ is a correlation function of x and y.

We call X a ZCZ sequence set of type $Z(L, N, z)$. If X exists, the parameters are restricted such that

$$N(z+1) \leq L.$$

The value $\frac{N(z+1)}{L}$ is a performance characteristic for the method of generating ZCZ sequence sets.

Despite the restriction on these parameters, there may exist an integer $z_0 > z$ and a pair of sequences x and y, such that

$$R_{x,y}(\tau) = 0 \text{ for } |\tau| \leq z_0.$$

We would like to develop a method to generate a ZCZ sequence set and determine pairs of obtained sequences whose zero-correlation zone size is bigger than that of the entire ZCZ sequence set.

To treat such problems, we generalize the concept of a ZCZ sequence set and introduce a ZCZ sequence set with a subset structure.

Let L, M, N, z, and Z be integers. A ZCZ sequence set with a subset structure of type $\tilde{Z}(L, M, N, z, Z)$ is a set of sequences X that satisfies the following properties:

(1) X is a ZCZ sequence set of type $Z(L, MN, z)$;

18

(2) There exists a set of subsets of X, $\{X_k\}_{k=0}^{M-1}$, such that

$$X = \bigcup_{k=0}^{M-1} X_k, \text{ (disjoint union), and}$$

$\#(X_k)$(cardinality of a subset X_k) $= N$;

(3) The ZCZ size of the cross-correlation function of the sequences chosen from different subsets (intersubset cross-correlation function) is Z.

In the first part of this thesis, three methods for creating ZCZ sequence sets with subset structures are presented. The first method is characterized by using Hadamard matrices and is described in **Chapter 2**. We begin with two Hadamard matrices of size n_0 and a Hadamard matrix of size n_1, extract sequences from these matrices, pad the sequences with 0s, and interleave them. We thus succeed in generating a ternary ZCZ sequence set with a subset structure of the type $\tilde{Z}(n_0^{m+2}(n_1+\Delta), n_0, n_1, n_0^{m+1}-1, \Delta n_0^{m+1})$, where m and Δ are arbitrary positive integers. The performance characteristic $\frac{N(z+1)}{L}$ is $\frac{n_1}{n_1+\Delta}$, and the size of the zero-correlation zone of the intersubset cross-correlation function is almost Δ times that of the ZCZ sequence set. For sufficiently large n_1, the characteristic is close to 1, which indicates that this method is almost optimal.

The second method, described in **Chapter 3**, is characterized by using Hadamard matrices and a perfect sequence. Let us assume that there exist a perfect sequence of length L_p and Hadamard matrices of size L_g and L_d. Under some conditions on these values, we are able to generate a ternary ZCZ sequence set with a subset structure of the type $\tilde{Z}(L_g L_b L_p, L_g, L_b N_d, Z, (\Lambda + 1)Z)$, where L_b, N_d, Z, and Λ are obtained from L_p, L_g, and L_d. The performance characteristic $\frac{N(z+1)}{L}$ is $\frac{L_p-\Lambda}{L_p}$, and the size of the ZCZ of the intersubset cross-correlation function is $\Lambda+1$ times of that of the total ZCZ sequence set. For sufficiently large L_p, the characteristic is close to 1, which indicates that this method is almost optimal.

The third method, described in **Chapter 4**, is characterized by using a single Hadamard matrix. Let us assume that there exists a Hadamard matrix of size n. We are able to generate a ternary ZCZ sequence set with a subset structure of the type $\tilde{Z}(2^{2m+6}(n+1), 2(2^{m+2}-1), 2n, 2^{m+2}, 2^{m+2})$, where m is an arbitrary nonnegative integer. The performance characteristic $\frac{N(z+1)}{L}$ is $\frac{n}{n+1} \cdot \frac{2^{2m+4}-1}{s^{2m+4}}$. In this method, the subsets correspond to the set $\{0, 1, 2, \cdots, N-1\}$, and the size of the ZCZ of the sequences of the subsets of k_1 and k_2 is approximately $2|k_1-k_2|-1$ times the size of the total ZCZ.

The second part of the thesis is a parameterization of perfect sequences, the definition of which is given intrinsically. If a sequence is expressed as $x = f(\alpha, \beta, \cdots, \gamma)$ by a known function

f with parameters $\alpha, \beta, \cdots, \gamma$, we can easily obtain a perfect sequence, and we can thus transform a problem of perfect sequences into a problem of the parameters $\alpha, \beta, \cdots, \gamma$. We developed a method in which the perfect sequence of real numbers is parameterized without using complex numbers. In **Chapter 5**, we introduce the concept of a quasi-perfect sequence. We reduce the problem of the parameterization of a perfect sequence of arbitrary length to the problems of the parameterization of a quasi-perfect sequence and the parameterization of a perfect sequence of odd length, both of which we then solve.

The concept of ZCZ sequence sets for two-dimensional sequences of real numbers promises to be useful for applications, such as for position control systems. We therefore investigated the theory of these sequence sets and successfully parameterized a two-dimensional perfect sequence of real numbers. We refer to a two-dimensional perfect sequence as a perfect array. In **Chapter 6**, we introduce the method of "near-diagonalization" of shift matrices. With this method, we were able to parameterize perfect arrays, and then, using these formulae, we found a series of perfect arrays of integers of size 6×6.

Another generalization of the theory of the zero-correlation zone sequence set of real numbers is the theory of these sets for a composition algebra over the real number field. A composition algebra is a generalization of the algebras of real or complex numbers; typical examples of these are the algebras of quaternions and octonions. Though it is not clear if applications exist, we investigated perfect sequences over such algebras. Since the algebras of neither quaternions nor octonions are commutative, we must pay attention to the order of multiplication. We have to consider both right perfect sequences and left perfect sequences. Kuzunezov showed that, in the algebra of quaternions, right perfection is equivalent to left perfection. In **Chapter 7**, we define perfect sequences for a composition algebra and use the method of "near-diagonalization" of shift matrices to successfully parameterize the sequences. Using this parameterization, we show that right perfection is equivalent to left perfection for any composition algebra.

In the case of the algebra of complex numbers, the discrete Fourier transform (DFT) is a powerful tool for the parameterization of perfect sequences. In the case of the algebra of quaternions or bigger algebras, we can easily construct many DFT-like transforms, but we do not know the relationships between them. Moreover, we cannot apply them for the parameterization of perfect sequences over such algebras. In **Chapter 8** we introduce the discrete sine transform (DST) and the discrete cosine transform (DCT). Using these transformations for sequences, we define the generalized discrete Fourier transform (GDFT) and clarify the relationship between the GDFTs. We also introduce the convolution of sequences and clarify the relationship between the convolutions, the DSTs, and the DCTs. Using these relationships, we prove a parameterization theorem that is equivalent to the theorem obtained by the method of "near-diagonalization".

Keywords: synthetic aperture radar, pulse compression, sequences, pulse compression method, zero-correlation zone sequence set, ternary sequence, zero-correlation zone, Hadamard matrix,

intersubset, correlation, intercell, mutually orthogonal complementary sets, parameterization, perfect array, perfect sequence, auto-correlation, perfect array, composition algebra, quaternion, octonion, Fourier analysis, associative law, commutative law

Summaries of the Dissertation Review Results

The review committee examined the academic ability of the applicant related with the following courses of the graduate school of the University of Aizu;

  CSA02 Generation of combinatorial Configurations,

  CSA11 Advanced Analysis,

  CSA14 Nonassociative Algebras and Lie Algebras.

The applicant presented proper answers to each question for the examination of the academic ability of the applicant.

As a result of the dissertation review, the dissertation has been recognized as qualified for conferment for an academic degree.

The applicant was requested to unify the mathematical notations in each chapter. The applicant was also required to remove the duplicated paragraphs in each chapter before the submission of the final draft of the dissertation.